

## ***Interactive comment on “Improved simulation of clouds over the Southern Ocean in a General Circulation Model” by Vidya Varma et al.***

**Anonymous Referee #2**

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### General Comments

Varma et al. perform global climate model (GCM) simulations with modified cloud parameterizations to investigate why GCMs underestimate cloud albedo over the Southern Ocean. This is a major and long-standing bias in GCMs. The authors investigate the hypothesis that albedo bias over the Southern Ocean is caused by an overly simplified treatment of ice-crystal shape that is used by current cloud parameterizations. The question that the authors investigate is important and fits within the scope of Atmospheric Chemistry and Physics. However, the study has some issues involving justification of the experimental design, discussion of the simulations, and clarity of the figures and writing. If these issues are addressed, then the manuscript might be acceptable for publication. I therefore recommend major revision.

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### Specific Comments

#### Title

I think “improved” is not appropriate to use in the title since the authors did not improve the theory on which the cloud parameterizations are based. Changing the tuning parameters in a model, as the authors have done in this study, is not the same thing as improving the model. I suggest that the title be changed to something like “Bias of Southern Ocean cloud albedo in a general circulation model linked to ice-crystal shape.”

#### Abstract

All of the abstract is fine except for the last sentence. The last sentence should be removed because the authors did not do any new work to justify this statement (“We hypothesize that such abundant supercooled liquid cloud is the result of a paucity of ice nucleating particles in this part of the atmosphere.”). It is unethical to make this statement in the abstract because the statement is based entirely on the work of others. It would be fine to include this statement in the discussion section with proper references, of course.

#### Data and Experimental Set-up

The experimental design needs to be explained and justified in more detail. For instance, the authors perform a sensitivity study in which the ice-crystal shape is modified. This is done by multiplying the “capacitance” (C) value by a factor of 0.5, which effectively changes the ice-crystal shape from spheres to ellipsoids. However, the authors do not cite any theoretical or observational work to justify their choice of 0.5 until the Discussion section (pg. 6 line 8), and even there it is simply stated that the choice of C is reasonable without any explanation. More background information justifying the choice of C=0.5 is needed in Section 2.1. It would also be nice if the authors provided some justification for their choice that is based on in situ observations over

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the Southern Ocean, perhaps from the recent SOCRATES field campaign. A second issue is that, as far as I can tell, some of the simulations and discussion are unrelated to the study goals. Simulations exp2 and exp3 use modified temperatures for ice nucleation in the convection and microphysics parameterizations. How do these experiments contribute to the goal of understanding how ice-crystal shape affects Southern Ocean cloud albedo? Also, the control simulation is compared to older versions of the model with no explanation of how this comparison helps to understand the cause of the cloud albedo bias in the current model (pg. 5 line 20, Figure 6). I do not understand the value of exp2, exp3, or the older versions of the model presented in Figure 6. Please discuss this or remove the content.

#### Results and Discussion

The Results section is hard to follow. It would help to organize the figures and text in a consistent way. The text discusses model bias in the TOA and surface energy budget terms one at a time, so it would be helpful if the data presented in Figure 3-5 were also organized based on different energy budget terms. For instance, Figure 3 could have one panel that shows LW TOA in ctrl, exp1, exp2, and exp3; another panel that shows SW TOA in ctrl, exp1, exp2, and exp3; and so on. Since model bias is the quantity of interest, it would also help to show all of the anomalies relative to observed values (e.g. ctrl – obs, exp1 – obs, exp2 – obs, exp3 – obs) rather than anomalies relative to the ctrl experiment in some of the panels and anomalies relative to observations in other panels. Another issue is that the content of the Discussion section doesn't seem to logically follow from the content of the Results section. The Results section describes how the model biases change as a result of the modifications to the cloud parameterizations, which is fine. But no clear conclusion about what was learned from these simulations is reached in the Discussion section. Should other modeling groups change the ice crystal shape in their models? If so, what range of capacitance values is suggested by observations and theory, and what values do the authors recommend using? How much of the Southern Ocean cloud albedo bias will be fixed by changing

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the ice-crystal shape? Please make a clear statement about what was learned from your work before starting the discussion about how other studies say that ice-nucleating particles are the critical thing to study (pg. 6 line 31).

#### Technical Corrections

Figure 1 – Change axis label to “IWP (km/m<sup>2</sup>)” to match the rest of the text.

Figure 2 – Why is the range of the x-axis so much larger in 2a-b than in 2c-d? Make the axis range consistent across all panels.

Figure 2 – I suggest moving all of the information about cloud types from the figure caption to the main text.

Figure 3,4 – Please organize the data so that one panel shows one energy budget term only, and that all anomalies are shown relative to observations, as mentioned in my comments on “Results and Discussion” above.

Figure 6 – What value does this figure add to the study? I think this figure should be removed

Figure 7 – What does this figure show that isn't already shown in Figure 5? It shows a big response in the tropical western Pacific to changing the nucleation temperature, but this isn't relevant to understanding Southern Ocean cloud albedo biases.

Figure 6,7 – The colorbar makes these figures very difficult to read. Please change the colorbar to a two-color scale with white at zero. For example, the colorbar could have red for positive values, white for near-zero values, and blue for negative values.

Pg. 1 line 19 “observed radiation biases” – delete “observed”

Pg. 2 line 6 – specify that “this model problem” means cloud albedo bias over the Southern Ocean

Pg. 2 line 8 – I recommend moving the sentence “In the present study, we

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investigate. . .” to the end of the preceding paragraph and moving the sentence “Here, we define a SO. . .” to Section 2 Data and experimental set-up. I think it helps to finish the Introduction with a concise statement of the study goals, which is what the first sentence does.

Pg. 2 line 12 – Why isn’t this paragraph in section 2.1 Model set-up?

Pg. 2 line 13 – Is it necessary to put the model description in an appendix? Appendix A is only one paragraph long, after all. It improves the clarity of the paper if the reader doesn’t have to jump around between different sections.

Pg. 3 line 14 “parametrised convection scheme” – “parametrised” is redundant and can be deleted.

Pg. 4 line 8 – Why does modifying the capacitance value affect liquid and ice? Does the capacitance value control the diffusional growth of liquid droplets as well? If so, then I don’t think that  $C=0.5$  is realistic for liquid droplets. Also, why does changing the ice nucleation temperature predominantly affect IWP? I think other studies suggest that it should affect both LWP and IWP [e.g. Kay et al., 2016].

Pg. 4 line 11, Pg. 5 line 9, Pg. 5 line 19 – Please don’t just state that these figures are included in the supporting information. You need to say what the figures show and how they contribute to the findings of the study.

Pg. 4 line 17 – Why is the change in TOA LW flux so large in your simulations? LW radiation was not part of the motivation, yet TOA LW flux is more sensitive than TOA SW flux to the model modifications made in this study. Please explain this.

Pg. 4 line 22 – By “show an increase” do you mean an increase relative to the control experiment? Please clarify.

Pg. 5 line 1 – It would help to discuss the difference between the control simulation and observations first to establish the baseline model bias, then discuss how the bias changes in exp1-3. Please rearrange content accordingly.

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Pg. 6 line 18 “The atmosphere-only model studied here does perform better. . .” – Please use more specific language. For example, “model bias in SW CRE is reduced over the Southern Ocean.”

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